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Simultaneous BCI Operation and Electrophysiological Assessment to Identify Brain Signal Features for BCI-Based Rehabilitation

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Abstract. Brain-computer interface (BCIs) for motor rehabilitation might benefit from using brain signals which are tightly coupled to motor system function. We developed an open-source application to perform neurophysiological measurements during BCI use. We used this application to identify brain-signal features that correlated with corticospinal tract excitability independent of their task-related changes. Brain signal features that associate with desirable motor function are good candidates for use in BCI rehabilitation because the plasticity induced by operant conditioning of these features might also support improved motor function. Studies to investigate neurophysiological changes accompanying BCI training of these features are underway.

Keywords: Rehabilitation, plasticity, EEG, TMS, SMR

1. Introduction

One possible mechanism of BCI-based rehabilitation is that rewarding subjects to generate specific brain signals induces structural and functional plasticity in the CNS that facilitates the generation of the rewarded brain signals, and this plasticity also supports improved function [Daly and Sitaram, 2012]. Brain signals that, when rewarded, are likely to induce adaptive plasticity might be identifiable by their association with desirable motor behavior. We developed an open-source application to facilitate electrophysiological assessment during BCI use. In this report we describe the application and its use in identifying brain signals that correlate with corticospinal tract (CST) excitability indexed by the transcranial magnetic stimulation (TMS) induced motor-evoked potentials (MEP).

2. Material and Methods

We developed our experimental software using the BCI2000 platform [Schalk et al., 2004] and its BCPy2000 framework extension [Hill et al., 2007]. Within this environment, we created a flexible application for performing electrophysiological experiments capable of providing feedback about electrophysiological signals, gating task progression based on the properties of these signals, and triggering peripheral or central neural stimulation during the task. Feedback can be driven by electroencephalogram (EEG) activity, electromyogram (EMG) activity, or previously recorded data (i.e., sham). Feedback is provided as the position of a visual stimulus, the frequency of an auditory tone, or the intensity of muscle stimulation. The neural stimulation can be delivered via electrodes over the peripheral nerves or TMS over the brain and the stimulation intensity can be controlled manually or automatically. The stimulus-evoked response (e.g., M-wave or H-reflex for nerve stimulation, MEP for TMS) and its amplitude – or its residual amplitude after subtracting the modeled expected amplitude – can be displayed on the screen or used to control the stimulator intensity.

Seven (3 female) healthy right-handed individuals participated in this study. We recorded 31-channel EEG and left and right extensor dorsii communis (EDC) EMG low-pass filtered at 2 kHz and digitized at 5 kHz (BrainProducts). We did not use high-pass or notch filters so as to mitigate the size of the recorded TMS artifact. Participants were cued to perform right-hand finger extension or imagery upon cue offset. Visual feedback of EMG activation was provided during finger extension trials and participants were instructed to maintain EMG between 5-15% of maximum voluntary isometric contraction. Visual feedback of normalized μ-rhythm (typically 8-12 Hz) power from the C3 surface Laplacian derived signal was provided during 50% of imagery trials and participants were instructed to decrease power as much as possible. Four to six seconds after cue offset, TMS was delivered over the motor cortical representation of the right EDC at 120% resting motor threshold. Each participant performed 150 trials: 50 each of execution (EXEC), imagery with feedback (IMFB), and imagery without feedback (IMAG). Data were analyzed offline with EEGLAB [Delorme and Makeig, 2004].

3. Results

We identified two independent component clusters relevant to the task: the first cluster's dipoles localized to left medial frontal cortex (L_MF) and the second cluster's dipoles localized to left parietal area (L_Par). Activations from L_MF at cue-offset were greater during EXEC than the other tasks. Both cluster activations exhibited event-related desynchronization (ERD) in both μ- (8-12 Hz) and β- (17-25 Hz) bands. μ- and β-ERD persisted longer during IMFB trials than during IMAG trials.

MEPs were larger during IMFB trials than during IMAG trials. MEP size correlated positively with normalized upper-β power during IMFB trials (using subject-specific frequency-bands, $p < 0.001$). No other consistent correlations between spectral power and MEP size were observed.

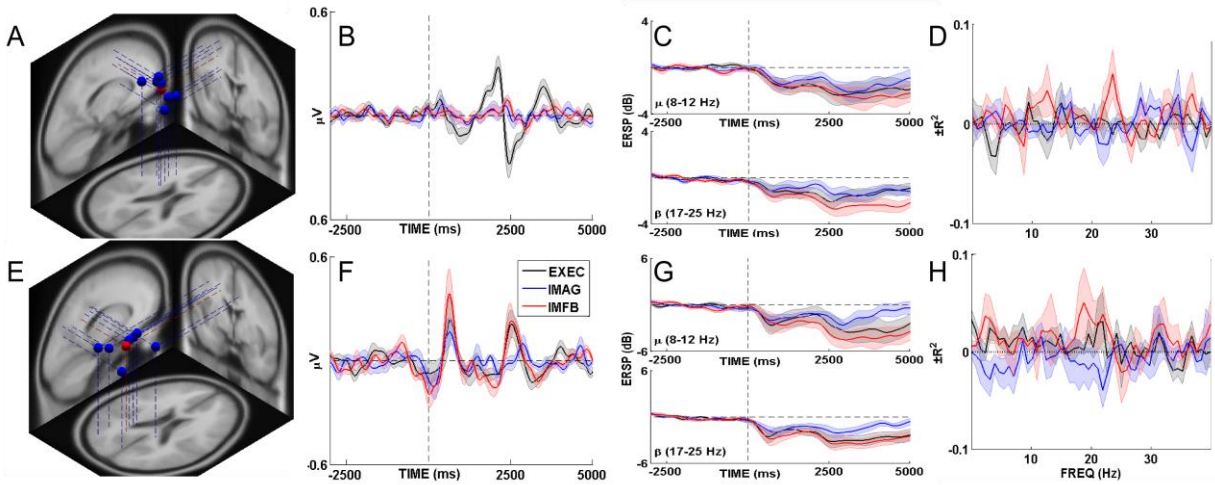

Figure 1. *Dipoles (A,E), event-related potentials (B,F), μ- and β-ERD (C,G), and signed spectral correlations with MEP size (D, H) for clusters L_MF (A-D) and L_Par (E-H).Values were calculated separately for motor execution (black), imagery without feedback (blue), and imagery with feedback (red). Shading indicates ± standard error.*

4. Discussion

We developed and made-available a flexible application for performing various neurophysiological measurements during BCI use. In this preliminary study, we used this software to identify brain signal features that may be suitable for BCI-based rehabilitation. Specifically, signal features that localized to contralateral sensorimotor cortices exhibited typical μ- and β-band ERD, but only those which localized to L_MF activated specifically during motor execution and only L_MF upper-β power correlated significantly with CST excitability.

Both μ- and β-band ERD, at both tested locations, persisted longer during IMFB trials than IMAG trials. Since TMS was delivered at the end of a trial, μ and β power was greater in the interval preceding IMAG MEPs than the interval preceding IMFB MEPs. Additionally, IMAG MEPs were smaller than IMFB MEPs. Thus, MEP size appears to correlate negatively with μ and β power when combining IMAG and IMFB trials, opposite to the MEP correlation with SMA β power observed during IMFB-only trials.

We interpret these conflicting results as follows: topographically diffuse μ- and β-ERD indicates engagement in a motor task and this engagement is also associated with increased CST activation, but within-task CST excitability is indicated by increased synchronization at upper-β in medial frontal cortex. It is as yet unclear whether adaptive plasticity would be better facilitated by BCI training with features that indicate motor task engagement or by BCI training with features that indicate within-task excitability. Studies investigating changes in motor physiology accompanying BCI training using both types of features are underway.

References

Daly JJ, Sitaram R. BCI therapeutic applications for improving brain function. In: Wolpaw JR, Wolpaw EW (Eds.). *Brain-Computer Interfaces: Principles and Practice*. Oxford: Oxford University Press, 351–362, 2012.

Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Meth*, 134:9–21, 2004.

Hill NJ, Schreiner T, Puzicha C, Farquhar J. BCPy2000, http://bci2000.org/downloads/BCPy2000, 2007.

Schalk G, McFarland DJ, Hinterberger T, Birbaumer N, Wolpaw JR. BCI2000: a general-purpose brain-computer interface (BCI) system. *IEEE Trans Biomed Eng*, 51:1034-1043, 2004.